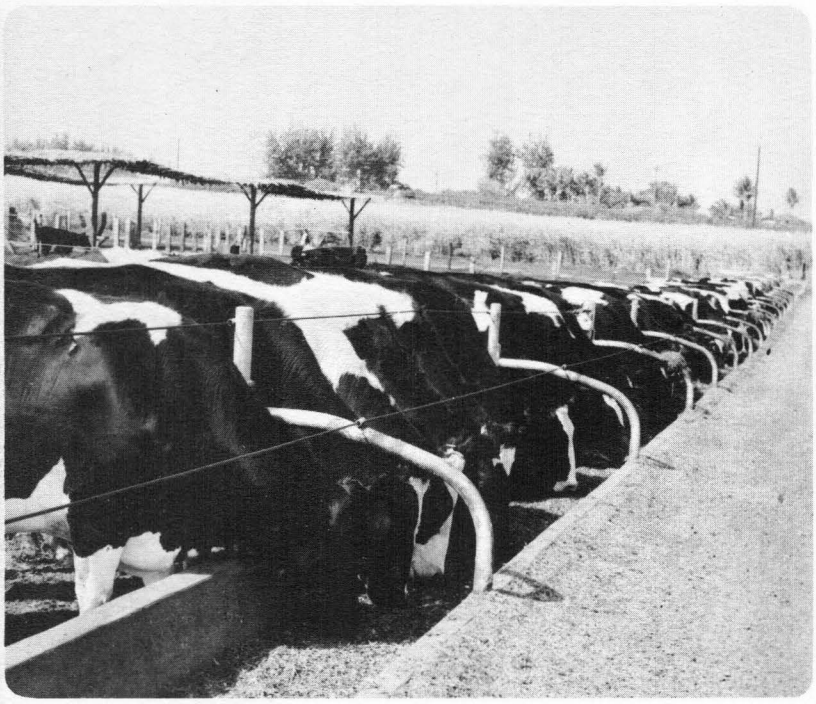

An Example of Least-Cost Rations for Oahu Dairies

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AN EXAMPLE OF LEAST-COST RATIONS FOR OAHU DAIRIES

Douglas J. McConnell,[1/] Richard W. Stanley,[2/] and Mao Lin Liu[3/]

INTRODUCTION

The dairy industry in Hawaii is dependent upon imports: cows, feed, and equipment are largely imported from the Mainland. Among the feeds available in quantity to dairymen on the island of Oahu, only pineapple bran, pineapple silage, pineapple hay, and molasses originate in Hawaii. Limited amounts of alfalfa, Rhodes grass, and Napier grass are also available. The great bulk of the dairy feed must be imported from the U. S. Mainland and foreign countries. Such heavy dependence on imported supplies contributes to the high cost of milk production in Hawaii.

Feed cost is by far the largest single item in the cost of producing milk. In 1959, feed costs alone accounted for 45.6 percent of total costs of producing milk on Oahu.[4/] This figure far surpasses any other single cost item. The cost of feed to Oahu dairies is high not only as a percentage of total costs but also in actual dollar terms when compared with costs in other states.

Linear programming is an analytical tool which has been widely used elsewhere in the United States for determining least-cost livestock rations. To test the feasibility of using programming in Hawaii, a representative dairy feeding problem has been solved by this method and the results are summarized in this report.

THE PROBLEM

Dairy cattle rations were computed utilizing two qualities of roughages, good and medium, and for animals producing at 30, 40, and 50 pounds of milk. A total of six different rations were computed:

(1) Ration for cows receiving good quality roughage and producing 30 pounds of milk.

(2) Ration for cows receiving medium quality roughage and producing 30 pounds of milk.

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(3) Ration for cows receiving good quality roughage and producing 40 pounds of milk.

(4) Ration for cows receiving medium quality roughage and producing 40 pounds of milk.

(5) Ration for cows receiving good quality roughage and producing 50 pounds of milk.

(6) Ration for cows receiving medium quality roughage and producing 50 pounds of milk.

After computing these rations they were evaluated on the following bases:

(1) Meeting the nutritional requirements as outlined.

(2) The ability of the cow to consume the quantities of roughage and concentrates fed.

(3) The palatability of the concentrate mixture as gauged by composition.

(4) The cheapest ration possible under the conditions of the problem.

TYPE OF ANIMAL SELECTED

Rations were formulated to provide the nutritional requirements for an average dairy cow. A mature milking cow weighing 1,300 pounds was selected. She was considered to be in good body condition and not more than 6 months pregnant. Rations were formulated for this cow producing at 30, 40, and 50 pounds of 3.75 percent butterfat daily.

NUTRIENT REQUIREMENTS

The nutrient requirements of the 1,300-pound cow are described below. The animal should receive at least 9.1 pounds of Total Digestible Nutrients (TDN) and 0.78 pound of Digestible Protein (DP) daily for maintenance. An additional 0.31 pound of TDN and 0.05 pound of DP are required for each pound of 3.75 percent butterfat milk produced daily. The basis of these nutritional requirements is illustrated in table 1. Consideration was given to both Morrison's Feeding Standards and the National Research Council Standards. Also because protein is an expensive item in dairy rations, the minimum amount of protein required is indicated. All requirements are on a daily basis. The requirements of the 30-, 40-, and 50-pound-producing cows are summarized below.

(1) 30-pound-producing cows: 18.4 pounds of TDN and 2.28 pounds of DP are required daily, or 1,840 pounds of TDN and 228 pounds of DP are required on a 100-head basis daily.

(2) 40-pound-producing cows: 21.5 pounds of TDN and 2.78 pounds of DP are required per head daily, or 2,150 pounds of TDN and 278 pounds of DP are required on a 100-head basis daily.

(3) 50-pound-producing cows: 24.6 pounds of TDN and 3.28 pounds of DP are required per head daily, or 2,460 pounds of TDN and 328 pounds of DP are required on a 100-head basis daily.

Table 1. Nutritional requirements of milking dairy cattle

Item	National Research Council[1/]		Morrison's Feeding Standards[2/]		Nutritional Standards used in calculating rations	
	Digestible Protein (DP)	Total Digestible Nutrient (TDN)	Digestible Protein (DP)	Total Digestible Nutrient (TDN)	Digestible Protein (DP)	Total Digestible Nutrient (TDN)
	Pounds daily					
Maintenance, 1,300-pound cow	0.75	8.5	0.75 -0.82	8.6 -9.6	0.78	9.1
Milk production (per pound of milk--3.75 percent fat)	0.044	0.31	0.044-0.056	0.295-0.310	0.050	0.31

1/ Nutrient Requirements of Domestic Animals. No. 3--Nutrient Requirements of Dairy Cattle--Revised 1958. National Academy of Sciences, National Research Council, Publication 464.

2/ Feeds and Feeding, by Frank B. Morrison, 22nd edition, 1959.

FEED ITEM RESTRICTIONS

In order that the feeding program would be practical and not based entirely on cost of feed items, certain restrictions had to be imposed.

A. Roughage

The upper and lower limits of roughage items that were determined for this study are shown in table 2. The basis for roughage feeding was the hay equivalent intake (HE). One HE is equal to 1 pound of hay per 100-pound body weight of the animal. In other words, a 1,300-pound cow receiving 1 HE would receive 13 pounds of hay daily.

The lower limit of 1 HE was set for the roughage feeding program. The upper limit was set depending upon the quality of the roughage fed. Feeding a medium quality roughage, the animal should consume 1.38 HE or a total of 18 pounds of roughage daily, whereas if good quality roughage were fed she should consume 1.85 HE or a total of 24 pounds of roughage daily. These amounts were considered to be the maximum amount of roughage that a 1,300-pound animal would consume daily.

When combinations of roughages were considered, the animal was to receive at least 13 HE and not more than 18 or 24, depending upon the quality of roughage.

Table 2. Restrictions of roughage items, 100 cows per day

Roughage item		30-G	30-M	40-G	40-M	50-G	50-M
		Pounds	Pounds	Pounds	Pounds	Pounds	Pounds
Roughage	≫ [1]	1,300	1,300	1,300	1,300	1,300	1,300
Roughage	≪ [2]	2,400	1,800	2,400	1,800	2,400	1,800
Pineapple bran	≪	2,200	2,200	2,200	2,200	2,200	2,200
Pineapple silage	≪	5,000	5,000	5,000	5,000	5,000	5,000
Pelleted pineapple hay	≪	1,300	1,300	1,300	1,300	1,300	1,300
Loose pineapple hay	≪	910	910	910	910	910	910
Alfalfa meal	≪	2,400	1,800	2,400	1,800	2,400	1,800
Alfalfa hay	≪	2,400	1,800	2,400	1,800	2,400	1,800
Rhodes grass hay	≪	2,000	-	2,000	-	2,000	-
Sudan grass hay	≪	2,000	1,500	2,000	1,500	2,000	1,500

1/ ≫ Should receive the amount shown in the table.
2/ ≪ Should not receive more than the amount shown in the table.

The conversion ratios of roughage items to hay equivalents are shown below:

1 pound of pelleted alfalfa meal = 1 HE

1 pound of hay

a. Alfalfa
b. Sudan grass
c. Pelleted pineapple hay
d. Loose pineapple hay = 1 HE

1 pound of pineapple silage = 0.22 HE
(moisture above 80 percent)

1 pound of pineapple silage = 0.25 HE
(moisture 75 to 80 percent)

Feeding the roughage items individually, the 1,300-pound cow would be expected to consume no more than the following amounts along with sufficient concentrate and pineapple bran to provide the daily nutrient requirements.

Roughage	Pounds daily
Sudan grass hay	
a. Good quality.	20
b. Medium quality.	15

Roughage	Pounds daily
Rhodes grass hay	
a. Good quality	20
b. Medium quality	15
Alfalfa hay or pellets	
a. Good quality	24
b. Medium quality	18
Pelleted pineapple hay	13
Loose pineapple hay	9
Pineapple silage	50

A limit of 22 pounds per cow per day was placed on pineapple bran. With these restrictions imposed, it was decided that a practical ration could be formulated utilizing the linear programming system. As mentioned earlier, the rations were checked after computing to assure that they were practical.

B. Concentrate

While considerable restrictions were placed on roughage in order to insure the formulation of a ration which would be consumed, lesser restrictions were required for the concentrate portion of the ration. For concentrates, restrictions were imposed to insure a palatable mixture. In order to accomplish this, maximum percentage levels of each concentrate which may come into the ration were established. The maximum percentage level of each concentrate item used in this study is shown below.

Concentrate	Maximum percentage of total mix
Barley	60
Copra	50
Corn distillers grain	50
Corn gluten feed	50
Millrun	35
Shelled corn	50
Wheat	35

That is, barley, if it enters the solution at all, should not exceed 60 percent of the total concentrate mix, copra should not exceed 50 percent of the total mix, etc.

Molasses was limited to 4.5 pounds per cow per day, or 450 pounds for a 100-cow herd.

COMPOSITION OF FEEDSTUFFS

A. Roughage

The total digestible nutrients and digestible protein content of various roughages are shown in table 3.

Table 3. Composition of feedstuffs

Roughage item	Good quality			Medium quality		
	DM	TDN	DP	DM	TDN	DP
	Percent	Percent	Percent	Percent	Percent	Percent
Alfalfa meal (15 percent protein guarantee)	91.6	52.8	10.8	91.6	52.8	10.8
Alfalfa hay	90.5	50.3	10.2	90.5	46.3	8.2
Pineapple bran	-	64.5	0.6	-	64.5	0.6
Pineapple silage	19.0	11.0	0.4	19.0	11.0	0.4
Pelleted pineapple hay	-	47.0	1.5	-	47.0	1.5
Loose pineapple hay	-	47.0	1.5	-	47.0	1.5
Sudan grass hay	89.6	50.0	6.3	89.6	48.6	4.3
Rhodes grass hay	89.0	51.4	2.6	89.0	41.1	2.1

Most of the nutritional values of roughage items were obtained from Morrison.[5/] Some were obtained from nutritional studies conducted at the University of Hawaii.

B. Concentrate

The composition of concentrate items is summarized in table 4. The composition table for concentrate items is also based on Morrison and similar work done at the University of Hawaii. The nutritional values used are comparable to the nutritional value of concentrates used by Oahu dairies.

Table 4. Composition of concentrate

Concentrate item	TDN	DP
	Percent	Percent
Barley (Pacific Coast States)	78.8	6.9
Copra (expeller or hydraulic process)	77.1	18.0
Corn distillers grain (without soluble)	84.0	19.1
Corn gluten feed (all analysis)	74.1	21.3
Millrun (wheat mixed feed, all analysis)	70.1	16.6
Shelled corn (corn dent, Grade No. 2)	80.1	6.7
Wheat (Pacific Coast States)	79.9	8.3
Molasses (cane)	60.5	1.1
Cottonseed meal (41 percent protein)	71.7	33.3
Linseed meal (expeller or hydraulic process, all analysis)	75.5	30.6
Milo grain	79.4	8.5
Oats (Pacific Coast States)	72.2	7.0
Soybean meal (solvent)	78.0	42.0

5/ See Reference 2.

PRICES OF FEEDSTUFFS

A. Roughage

The prices of roughages used in this study are summarized in table 5.

Table 5. Roughage prices, Oahu, October, 1962

Roughage item	Price per ton	
	Good quality	Medium quality
	Dollars	Dollars
(1) Alfalfa meal	75.00	75.00
(2) Alfalfa hay	60.00	50.00
(3) Pineapple bran	53.00	53.00
(4) Pineapple silage	9.60	9.60
(5) Pelleted pineapple hay	47.00	47.00
(6) Loose pineapple hay	45.00	45.00
(7) Rhodes grass hay	45.00	N.A.[1/]
(8) Sudan grass hay	42.00	42.00

1/ Not available.

Sources: Items 1 and 3--major feed mill, Honolulu.
Items 4, 5, and 6--supplying plantation, Oahu.
Items 2 and 7--Hawaii Cooperative Extension Service.
Item 8--supplying ranch, Molokai.

The quality of pineapple bran, pineapple silage, pelleted pineapple hay, loose pineapple hay, and alfalfa meal is assumed to be the same throughout the year; therefore, prices of these items are unchanged for both good and medium quality. Sudan grass hay of medium quality has the same price as that of good quality because of short supply during the off (poor quality) season. Pineapple silage was quoted at $7.50 per ton by one major Oahu supplier. The estimated cost of hauling pineapple silage from the pickup point to the farm is $2.10 per ton; this is added to give a final price of $9.60 per ton. The cost of hauling pelleted pineapple hay and loose pineapple hay ($2.00) is also added to the base prices of these items.

B. Concentrate

The prices of concentrate items are summarized in table 6.

Table 6. Price of concentrate, October, 1962

Concentrate item	Price per ton[1/]	Cost of hauling per ton
	Dollars	Dollars
Barley	86.00	2.00
Copra	102.00	2.00
Corn distillers grain	123.40	2.00
Corn gluten feed	87.00	2.00
Millrun	92.60	2.00
Shelled corn	85.00	2.00
Wheat	109.60	2.00
Molasses	23.20	1.70
Cottonseed meal	109.00	2.00
Linseed meal	130.00	2.00
Milo	81.00	2.00
Oats	110.80	2.00
Soybean meal	129.00	2.00

1/ Includes cost of hauling feedstuff from the pickup point to the farm.

Source: Major feed mill, Honolulu.

Concentrate prices include costs of hauling and are equivalent to costs of the various feed items delivered in bulk to the farm. The cost of hauling is estimated at $2.00 per ton for all concentrate items except molasses. The cost of hauling molasses is estimated at $1.70 per ton.

30-G: RATION FOR COWS RECEIVING GOOD QUALITY ROUGHAGE AND PRODUCING 30 POUNDS OF MILK DAILY

The least-cost ration for 30-pound-producing cows is summarized in table 7. Solution of this 30-G feed problem will be examined in some detail. Explanation will be less detailed for all subsequent rations.

The 30-pound-producing ration includes 364.4 pounds of Rhodes grass hay and 2,000 pounds of Sudan grass hay as roughage; and 52.6 pounds of cottonseed meal, 250 pounds of corn gluten feed, 197.4 pounds of milo, and 450 pounds of molasses, for 100 cows per day. Cost of feeding 100 cows is $77.16 per day. Total digestible nutrients and digestible protein requirements are exactly met (compare with Nutrient Requirements in table 1).

Table 7. Daily ration for 100 cows receiving good quality roughage and producing 30 pounds of milk daily

Feed item	Quantity	TDN	DP	Cost
	Pounds	Pounds	Pounds	Dollars
Rhodes grass hay	364.4	187.3	9.5	8.20
Cottonseed meal	52.6	38.4	17.5	2.87
Sudan grass hay	2,000.0	1,000.0	126.0	42.00
Corn gluten feed	250.0	185.3	53.3	10.88
Milo	197.4	156.7	16.8	7.99
Molasses	450.0	272.3	5.0	5.22
Total	3,314.4	1,840.0	228.1	77.16

This computed ration is optimal only on the basis of the feed item prices used above. If these prices change greatly, then one would expect the ration to change. If price changes are small, the ration might remain unchanged. It is useful to know how stable the ration is; i.e., the magnitude of feed item price changes necessary to induce changes in the composition of the computed ration. This information is printed out by the particular program used here and is presented in table 8.

Table 8. Price stability of 30-G ration

Feed item	Current price	Upper price limit	Upper range	Percentage of price increase	Entering activity
	Dollars	Dollars	Dollars	Percent	
Rhodes grass hay	45.00	45.09	0.09	0.20	Pineapple bran
Cottonseed meal	109.00	112.22	3.22	2.95	Soybean meal
Sudan grass hay	42.00	48.82	6.82	16.24	
Corn gluten feed	87.00	93.75	6.75	7.76	
Milo	81.00	82.03	1.03	1.27	Pineapple bran
Molasses	23.20	50.32	27.12	116.90	

Rhodes grass hay is an unstable item: a very slight increase in the price of Rhodes grass hay, slightly more than 0.20 percent above the current price, will force Rhodes grass out of the optimal ration and replace it with pineapple bran. Cottonseed meal and milo are also not too stable. If the price of cottonseed meal increases by more than 2.95 percent above the current price, cottonseed meal will be forced out and replaced by soybean meal. Similarly, if the price of milo increases by more than 1.27 percent, or from $81.00 to $82.03 per ton, it

will be forced out and replaced by pineapple bran. Sudan grass hay, corn gluten feed, and especially molasses are very stable. Sudan grass hay would remain in the ration until the price increases by more than 16.24 percent. In the same manner, corn gluten feed would remain in the ration until the price increases by more than 7.76 percent. Molasses also would remain in the ration until the price increases by more than 116.90 percent. The right-hand column heading "Entering activity" shows those feed items which are not in the present ration but which would come in if the prices of the respective ration items increase above the limits shown in the "Upper price limit" column. For example, if cottonseed meal increases in price by more than 2.95 percent to any level above $112.22, cottonseed would be replaced in the ration by soybean meal.

The practical usefulness of this information is obvious: it gives at a glance the price limits of feed items above which these items would no longer be purchased. It also warns the feeder to pay particular attention to price movements of the unstable items in his ration.

The dairyman might not like the particular 30-pound-producing ration computed above. He might want to substitute some feed items which are not included in the ration for items which are included. If he substitutes feed items which were not included in the ration for items which were included, the cost will naturally be somewhat higher, depending on the extent by which his substitutions depart from the least-cost optimal solution. We also have this information printed out by the program.

Penalty costs of forcing other items into the computed ration are shown in table 9. These penalty costs exist in the sense that the total cost of the ration ($77.16) would increase if a unit of these various feed items was forced into the computed ration. The penalty cost is not equal to the price of the feed item itself. When a unit of this feed item is forced in, some other items in the ration would be forced out, so that the total nutrient requirements may be still exactly met. The penalty costs shown in the second column apply only over limited ranges for the various items: these are shown in the third column. For example, by forcing alfalfa hay into the ration (which does not now contain alfalfa) the cost of the ration is increased by $5.72 per ton, but only up to a limit of 0.0864 ton. In other words, each pound of alfalfa added to the ration up to 172 pounds (0.0864 ton) would increase the total cost of the ration by 0.286 cent. What the penalty cost would be if more than 0.0864 ton of alfalfa was forced in we do not know. But the limited information we do have regarding these penalty costs is usually sufficient to allow the feeder to consider alternative feeds.

Similarly, the computed ration is based on specified minimum levels of TDN and DP: if now it is desired to increase these nutrient levels, this can be done but at an increased ration cost. For example, the DP minimum requirement was 228 pounds for the 30-pound-producing herd. If now a higher level of DP is required, the information presented in table 9 shows that more DP included in the ration would increase ration costs by 6.7 cents per pound of additional DP--up to a limit of 50 pounds.

Penalty cost information is similar to the price stability values shown in table 8. Thus, it will be recalled, relatively small price increases in Rhodes grass hay, cottonseed meal, and milo would force these items out, and bring in

Table 9. Cost of substituting feeds in the 30-G ration

Item activity forced into ration	Penalty cost per unit of item forced into ration	Range of entering activity over which penalty cost applies
Feed	Dollars	Tons
Alfalfa hay	5.72	0.0864
Copra	10.25	0.0688
Corn distillers grain	24.55	0.0638
Millrun	14.97	0.0875
Wheat	28.48	0.0875
Soybean meal	4.30	0.0197
Linseed meal	22.60	0.0296
Shelled corn	5.86	0.0919
Oats	37.65	0.0943
Pineapple silage	0.18	0.8547
Pelleted pineapple hay	4.38	0.1981
Loose pineapple hay	2.37	0.1981
Alfalfa meal	17.89	0.0814
Pineapple bran	0.11	0.1467
Barley	7.69	0.0928
Pounds	Dollars	Pounds
TDN increase	0.0403	18.46
DP increase	0.0670	49.57

as substitutes those items shown under "Entering activity" in the last column. Therefore, we would expect these "entering activities" (items not now in the ration but which are "close to entering") to have relatively low penalty costs. And looking at the penalty cost information this is just what we do find. Of all the concentrate items not in the ration, soybean meal has the lowest penalty cost, and pineapple bran (the other item that is "nearly in" the ration) has a penalty cost of only $0.11 per ton.

The solution of the 30-G feed problem and the additional information relating to this solution will be briefly summarized:

1. The solution (least-cost ration) itself is given above in terms of both pounds of various feed items and price of the composite ration.

2. The price stability of these ration items is also described in terms of "percentage of price increase" allowable before items are forced out. Also, for those unstable items which would be forced out, the substitute items are shown ("entering activities").

3. Penalty costs of forcing nonration items into the ration are given, and also the ranges over which these penalty costs apply.

4. Costs of increasing TDN and DP levels of the ration are also shown.

30-M: RATION FOR COWS RECEIVING MEDIUM QUALITY ROUGHAGE AND PRODUCING 30 POUNDS OF MILK DAILY

The least-cost ration for 30-pound-producing cows with medium quality roughage is shown in table 10.

Table 10. Daily ration for 100 cows receiving medium quality roughage and producing 30 pounds of milk daily

Feed item	Quantity	TDN	DP	Cost
	Pounds	Pounds	Pounds	Dollars
Pineapple bran	487.8	314.6	2.9	12.93
Cottonseed meal	206.8	151.0	68.9	11.27
Milo	143.2	113.7	12.2	5.79
Corn gluten feed	350.0	259.4	74.6	15.23
Sudan grass hay	1,500.0	729.0	64.5	31.50
Molasses	450.0	272.3	5.0	5.22
Total	3,137.8	1,840.0	228.1	81.94

Again, the minimum TDN and DP requirements are exactly met. This 30-M ration includes the following items: 487.8 pounds of pineapple bran, 206.8 pounds of cottonseed meal, 143.2 pounds of milo, 350 pounds of corn gluten feed, 1,500 pounds of Sudan grass hay, and 450 pounds of molasses for 100 cows per day. Cost of feeding 100 cows is $81.94 a day (compared with $77.16 for 30-G ration). It consists of the same items as the 30-G ration except that pineapple bran is now in and Rhodes grass hay has gone out.

The stability of the solution is shown in table 11.

Table 11. Price stability of 30-M ration

Feed item	Current price	Upper price limit	Upper range	Percentage of price increase	Entering activity
	Dollars	Dollars	Dollars	Percent	
Pineapple bran	53.00	53.88	0.88	1.66	Pineapple silage
Cottonseed meal	109.00	112.20	3.20	2.94	Soybean meal
Milo	81.00	86.54	5.54	6.84	Shelled corn
Corn gluten feed	87.00	93.77	6.77	7.78	
Sudan grass hay	42.00	45.09	3.09	7.36	
Molasses	23.20	50.43	27.23	117.37	

Pineapple bran is not very stable. An increase of only 1.66 percent in the price of pineapple bran would force it out and replace it with pineapple silage. Corn gluten feed, Sudan grass hay, and molasses are very stable. Corn gluten feed, for example, would remain in the ration in reduced amount even if the price increases by 7.78 percent. Molasses would remain in the ration for all prices up to $50.43.

Copra forced into the ration would increase costs by 0.507 cent for each pound added up to 0.1159 ton; corn distillers grain forced into the ration would increase costs by 1.22 cents for each pound added up to 0.1243 ton; etc. (see table 12). Similarly, the TDN content could be increased in the ration at a penalty of 4.04 cents per pound up to 1,106.91 pounds, and the DP content increased at a penalty of 6.69 cents per pound up to 35.56 pounds.

Table 12. Cost of substituting feeds in the 30-M ration

Item activity forced into ration	Penalty cost per unit of item forced into ration	Range of entering activity over which penalty cost applies
Feed	Dollars	Tons
Copra	10.15	0.1159
Corn distillers grain	24.50	0.1243
Barley	7.77	0.0672
Millrun	15.09	0.0820
Wheat	28.60	0.0709
Soybean meal	4.31	0.0767
Linseed meal	22.60	0.1162
Shelled corn	5.94	0.0666
Oats	37.75	0.0676
Pineapple silage	0.15	0.6818
Pelleted pineapple hay	4.25	0.1500
Loose pineapple hay	2.25	0.2142
Alfalfa hay	1.53	0.1500
Alfalfa meal	17.80	0.1500
Pounds	Dollars	Pounds
TDN increase	0.0404	1,106.91
DP increase	0.0669	35.56

40-G: RATION FOR COWS RECEIVING GOOD QUALITY ROUGHAGE AND PRODUCING 40 POUNDS OF MILK DAILY

The least-cost ration for 40-pound-producing cows with good quality roughage is shown in table 13.

Table 13. Daily ration for 100 cows receiving good quality roughage and producing 40 pounds of milk daily

Feed item	Quantity	TDN	DP	Cost
	Pounds	Pounds	Pounds	Dollars
Pineapple bran	221.4	142.8	1.3	5.87
Cottonseed meal	125.0	91.3	41.6	6.81
Milo	225.0	178.7	19.1	9.11
Sudan grass hay	2,000.0	1,000.0	126.0	42.00
Rhodes grass hay	400.0	205.6	10.4	9.00
Corn gluten feed	350.0	259.4	74.6	15.23
Molasses	450.0	272.3	5.0	5.22
Total	3,771.4	2,150.1	278.0	93.24

The ration for 40-pound-producing cows with good quality roughage includes 221.4 pounds of pineapple bran, 125 pounds of cottonseed meal, 225 pounds of milo, 2,000 pounds of Sudan grass hay, 400 pounds of Rhodes grass hay, 350 pounds of corn gluten feed, and 450 pounds of molasses. Cost of feeding 100 cows is $93.24 per day. The nutrient requirements are exactly met.

The stability of the solution is shown in table 14.

Table 14. Price stability of 40-G ration

Feed item	Current price	Upper price limit	Upper range	Percentage of price increase	Entering activity
	Dollars	Dollars	Dollars	Percent	
Pineapple bran	53.00	57.31	4.31	8.13	Concentrate item
Cottonseed meal	109.00	112.20	3.20	2.94	Soybean meal
Milo	81.00	82.14	1.14	1.41	Barley
Sudan grass hay	42.00	48.81	6.81	16.21	
Rhodes grass hay	45.00	45.10	0.10	0.22	Roughage item
Corn gluten feed	87.00	93.77	6.77	7.78	
Molasses	23.20	50.43	27.23	117.37	

Only Rhodes grass hay is unstable. A very slight change in the price of Rhodes grass hay (0.22 percent) would cause it to be forced out and replaced by another roughage. If the price of pineapple bran increases by 8.12 percent, pineapple bran would be forced out and replaced by some other concentrate item. This does not imply that use of a concentrate item is more economical than a roughage item, but only that there is no room for another roughage item to come in, because the maximum limit on roughage has been set at 2,400 pounds, which is already in the ration (2,000 pounds of Sudan grass hay and 400 pounds of Rhodes grass hay).

Sudan grass hay, corn gluten feed, and molasses are stable in this case. They could remain in the ration even if the price increases by up to 16.21, 7.78, and 117.37 percent, respectively.

The penalty costs are summarized in table 15.

Alfalfa hay forced into the ration would increase costs by 0.286 cent for each pound added up to 0.2000 ton. Copra forced into the ration would increase cost by 0.5075 cent for each pound added up to 0.1632 ton, etc. TDN and DP could be increased with a penalty of 4.04 and 6.69 cents up to 1,279 and 56 pounds, respectively.

Table 15. Cost of substituting feeds in the 40-G ration

Item activity forced into ration	Penalty cost per unit of item forced into ration	Range of entering activity over which penalty cost applies
Feed	Dollars	Tons
Alfalfa hay	5.72	0.2000
Copra	10.15	0.1632
Corn distillers grain	24.50	0.1472
Millrun	15.09	0.1225
Wheat	28.60	0.1115
Soybean meal	4.31	0.0463
Linseed meal	22.60	0.0702
Shelled corn	5.94	0.1048
Oats	37.75	0.1063
Pineapple silage	0.17	0.9090
Pelleted pineapple hay	4.35	0.2000
Loose pineapple hay	2.32	0.2857
Alfalfa meal	17.90	0.1899
Barley	7.77	0.1056
Pounds	Dollars	Pounds
TDN increase	0.0404	1,279.16
DP increase	0.0669	55.91

40-M: RATION FOR COWS RECEIVING MEDIUM QUALITY ROUGHAGE AND PRODUCING 40 POUNDS OF MILK DAILY

The least-cost ration for 40-pound-producing cows with medium quality roughage is shown in table 16.

Table 16. Daily ration for 100 cows receiving medium quality roughage and producing 40 pounds of milk daily

Feed item	Quantity	TDN	DP	Cost
	Pounds	Pounds	Pounds	Dollars
Pineapple bran	738.0	476.0	4.4	19.56
Cottonseed meal	282.2	206.0	94.0	15.38
Milo	167.8	133.2	14.3	6.79
Corn gluten feed	450.0	333.5	95.9	19.58
Sudan grass hay	1,500.0	729.0	64.5	31.50
Molasses	450.0	272.3	5.0	5.22
Total	3,588.0	2,150.0	278.1	98.03

The 40-M ration contains the same items as the 40-G ration except that Rhodes grass hay is omitted. Cost of feeding 100 cows is $98.03 a day, compared with $93.24 for the 40-G ration. Sudan grass hay and molasses come into the ration to their maximum limits.

The stability of the solution is shown in table 17.

Table 17. Price stability of 40-M ration

Feed item	Current price	Upper price limit	Upper range	Percentage of price increase	Entering activity
	Dollars	Dollars	Dollars	Percent	
Pineapple bran	53.00	53.88	0.88	1.66	Pineapple silage
Cottonseed meal	109.00	112.20	3.20	2.94	Soybean meal
Milo	81.00	86.54	5.54	6.84	Shelled corn
Corn gluten feed	87.00	93.77	6.77	7.78	
Sudan grass hay	42.00	45.09	3.09	7.36	
Molasses	23.20	50.43	27.23	117.37	

The solution is generally stable except for pineapple bran and cottonseed meal, which would be replaced by silage and soybean meal, respectively. Similarly, shelled corn would replace milo if the price of the latter increased to more than $86.54 per ton.

The penalty costs are shown in table 18.

Table 18. Cost of substituting feeds in the 40-M ration

Item activity forced into ration	Penalty cost per unit of item forced into ration	Range of entering activity over which penalty cost applies
Feed	Dollars	Tons
Copra	10.15	0.1358
Corn distillers grain	24.50	0.1457
Barley	7.77	0.0787
Millrun	15.09	0.0961
Wheat	28.60	0.0831
Soybean meal	4.31	0.1047
Oats	37.75	0.0792
Linseed meal	22.60	0.1585
Shelled corn	5.94	0.0781
Pineapple silage	0.15	0.6818
Pelleted pineapple hay	4.25	0.1500
Loose pineapple hay	2.25	0.2142
Alfalfa hay	1.53	0.1500
Alfalfa meal	17.80	0.1500
Pounds	Dollars	Pounds
TDN increase	0.0404	945.19
DP increase	0.0669	41.68

Copra forced into the ration would increase costs by 0.5075 cent for each pound added up to 0.1358 ton, a ton of corn distillers grain forced into the ration would increase costs by 1.225 cents for each pound added up to 0.1457 ton, etc. Similarly, TDN and DP could be increased at a penalty rate of 4.04 and 6.69 cents up to 945 and 42 pounds, respectively.

50-G: RATION FOR COWS RECEIVING GOOD QUALITY ROUGHAGE AND PRODUCING 50 POUNDS OF MILK DAILY

The least-cost ration for 50-pound-producing cows with good quality roughage for 100 cows would cost $109.33 per day. It is summarized in table 19.

It will be noted that the minimum TDN and DP requirements (see page 4) are exactly met.

Table 19. Daily ration for 100 cows receiving good quality roughage and producing 50 pounds of milk daily

Feed item	Quantity	TDN	DP	Cost
	Pounds	Pounds	Pounds	Dollars
Pineapple bran	471.6	304.2	2.8	12.50
Cottonseed meal	200.4	146.3	66.7	10.92
Milo	249.6	198.2	21.2	10.11
Sudan grass hay	2,000.0	1,000.0	126.0	42.00
Rhodes grass hay	400.0	205.6	10.4	9.00
Corn gluten feed	450.0	333.5	95.9	19.58
Molasses	450.0	272.3	5.0	5.22
Total	4,221.6	2,460.1	328.0	109.33

This ration includes 470 pounds of pineapple bran, 200 pounds of cottonseed meal, 250 pounds of milo, 2,000 pounds of Sudan grass hay, 400 pounds of Rhodes grass hay, 450 pounds of corn gluten feed, and 450 pounds of molasses.

The stability of the solution is given in table 20.

Table 20. Price stability of 50-G ration

Feed item	Current price	Upper price limit	Upper range	Percentage of price increase	Entering activity
	Dollars	Dollars	Dollars	Percent	
Pineapple bran	53.00	57.31	4.31	8.13	Concentrate item
Cottonseed meal	109.00	112.20	3.20	2.94	Soybean meal
Milo	81.00	82.14	1.14	1.41	Barley
Sudan grass hay	42.00	48.81	6.81	16.21	
Rhodes grass hay	45.00	45.10	0.10	0.22	Roughage item
Corn gluten feed	87.00	93.77	6.77	7.78	
Molasses	23.20	50.43	27.23	117.37	

Rhodes grass hay is very unstable. Rhodes grass hay is here a "borderline" item from the price viewpoint: an increase of only 0.22 percent would force out Rhodes grass hay. Sudan grass hay, corn gluten feed, and molasses are very stable. They could remain in the ration even if the price of Sudan grass hay, corn gluten feed, and molasses increased up to 16.21, 7.78, and 117.37 percent, respectively. Cottonseed meal and milo would be forced out and replaced by soybean meal and barley if the price of cottonseed meal and milo increases by 2.94 and 1.41 percent, respectively.

Penalty costs of forcing other items into the ration are shown in table 21.

Table 21. Cost of substituting feeds in the 50-G ration

Item activity forced into ration	Penalty cost per unit of item forced into ration	Range of entering activity over which penalty cost applies
Feed	Dollars	Tons
Alfalfa hay	5.72	0.2000
Copra	10.15	0.2022
Corn distillers grain	24.50	0.2168
Millrun	15.09	0.1431
Wheat	28.60	0.1237
Soybean meal	4.31	0.0743
Linseed meal	22.60	0.1125
Shelled corn	5.94	0.1163
Oats	37.75	0.1179
Pineapple silage	0.17	0.9090
Pelleted pineapple hay	4.35	0.2000
Loose pineapple hay	2.32	0.2857
Alfalfa meal	17.90	0.2000
Barley	7.77	0.1172
Pounds	Dollars	Pounds
TDN increase	0.0404	1,117.45
DP increase	0.0669	62.03

Alfalfa hay forced into the ration would increase cost by 0.286 cent per pound of alfalfa used up to 0.2000 ton. Copra forced into the ration would increase cost by 0.5075 cent per pound up to 0.2022 ton, etc. If, however, a feeder wanted to use more than 0.2000 ton of alfalfa hay, the penalty rate he would pay is not known, but it would be greater than 0.286 cent per pound.

TDN and DP could be increased at a penalty rate of 4.04 and 6.69 cents per pound up to 1,117 and 62 pounds, respectively.

50-M: RATION FOR COWS RECEIVING MEDIUM QUALITY ROUGHAGE AND PRODUCING 50 POUNDS OF MILK DAILY

The least-cost ration for 50-pound-producing cows with medium quality roughage is shown in table 22. The cost per 100 cows per day is now $114.20, compared with $109.33 for the 50-G (good roughage) situation.

Table 22. Daily ration for 100 cows receiving medium quality roughage and producing 50 pounds of milk daily

Feed item	Quantity	TDN	DP	Cost
	Pounds	Pounds	Pounds	Dollars
Pineapple bran	863.6	557.0	5.2	22.88
Cottonseed meal	300.6	219.4	100.1	16.38
Milo	299.4	237.7	25.4	12.12
Corn gluten feed	600.0	444.6	127.8	26.10
Sudan grass hay	1,500.0	729.0	64.5	31.50
Molasses	450.0	272.3	5.0	5.22
Total	4,013.6	2,460.0	328.0	114.20

This ration includes 863.6 pounds of pineapple bran, 300 pounds of cottonseed meal, 300 pounds of milo, 600 pounds of corn gluten feed, 1,500 pounds of Sudan grass hay, and 450 pounds of molasses. TDN and DP requirements are exactly met.

The stability of the solution is shown in table 23.

Table 23. Price stability of 50-M ration

Feed item	Current price	Upper price limit	Upper range	Percentage of price increase	Entering activity
	Dollars	Dollars	Dollars	Percent	
Pineapple bran	53.00	53.88	0.88	1.66	Pineapple silage
Cottonseed meal	109.00	112.20	3.20	2.94	Soybean meal
Milo	81.00	86.54	5.54	6.84	Shelled corn
Corn gluten feed	87.00	93.77	6.77	7.88	
Sudan grass hay	42.00	45.09	3.09	7.36	
Molasses	23.20	50.43	27.23	117.37	

The solution is stable except for pineapple bran and cottonseed meal, which would be replaced by silage and soybean meal, respectively. Corn gluten feed, Sudan grass hay, and molasses would remain in the ration even if the price increased up to 7.78, 7.36, and 117.37 percent, respectively.

Penalty costs of forcing other items into the ration are shown in table 24.

Table 24. Cost of substituting feeds in the 50-M ration

Item activity forced into ration	Penalty cost per unit of item forced into ration	Range of entering activity over which penalty cost applies
Feed	Dollars	Tons
Copra	10.15	0.2425
Corn distillers grain	24.50	0.2601
Barley	7.77	0.1406
Millrun	15.09	0.1716
Wheat	28.60	0.1484
Soybean meal	4.31	0.1115
Linseed meal	22.60	0.1688
Shelled corn	5.94	0.1395
Oats	37.75	0.1415
Pineapple silage	0.15	0.6818
Pelleted pineapple hay	4.25	0.1500
Loose pineapple hay	2.25	0.2142
Alfalfa hay	1.53	0.1500
Alfalfa meal	17.80	0.1500
Pounds	Dollars	Pounds
TDN increase	0.0404	864.08
DP increase	0.0669	74.41

Copra forced into the ration would increase ration costs by 0.5075 cent per pound, the same penalty as for the 50-G case, except that here the range is 0.2425 ton. Corn distillers grain forced into the ration would increase costs by 1.225 cents per pound up to 0.2601 ton, etc.

TDN and DP could be increased at a penalty rate of 4.04 and 6.69 cents per pound up to 864 and 74 pounds, respectively.

SUMMARY

A. Nutritional Aspects of Linear Programming

The six rations formulated will serve to illustrate certain nutritional aspects of feeding dairy cattle in Hawaii. For quick reference the six rations are summarized in table 25.

Table 25. Summary of six rations

Item	30-G	30-M	40-G	40-M	50-G	50-M
	Pounds daily					
Grain fed						
including pineapple bran	9.50	16.378	13.714	20.880	18.216	25.136
excluding pineapple bran	9.50	11.500	11.500	13.500	13.500	16.500
Hay consumed	23.6	15.0	24.0	15.0	24.0	15.0
Grain to milk ratio						
including pineapple bran	1:3.15	1:1.8	1:2.90	1:1.9	1:2.75	1:2.0
excluding pineapple bran	1:3.15	1:2.6	1:3.50	1:2.95	1:3.70	1:3.02
Cost per 100 cows	$77.16	$81.94	$93.24	$98.03	$109.33	$114.20

First of all, the importance of roughage contributing to the least-cost of milk production becomes clearly evident. All rations in which good quality roughage were utilized were cheaper than the respective rations utilizing only medium quality roughage. The differences in price in favor of the good roughage over the medium roughage were $4.78, $4.79, and $4.87 for the 30-, 40-, and 50-pound-producing cows, respectively. This difference remained constant even though the roughage intake was the same for the 30-, 40-, and 50-pound-producing cows. It is believed that the total roughage intake is not unrealistic; however, roughage consumption on the hay equivalent intake will be influenced by quality of roughage. Consideration was given to quality as seen by comparing 24 pounds consumed daily, or 1.85 hay equivalents intake for the good quality hay as compared to 18 pounds consumed daily, or 1.38 hay equivalents intake, for the medium quality hay. It is considered that because of Hawaii's warm climatic conditions less hay will be consumed than under mainland conditions. Hay equivalent intake for good to excellent quality hay under mainland conditions ranges from 2 to 3 hay equivalents per cow daily.

The contribution of the roughage can also be seen by comparing the grain-to-milk ratio for the six rations. These are shown below.

Level of production	Quality of hay	
	Good	Medium
30	1:3.15	1:1.8
40	1:2.90	1:1.9
50	1:2.75	1:2.0

The grain-to-milk ratio is much wider for the good quality hay than for the poor quality hay.

If one considers the grain-to-milk ratios excluding the pineapple bran, the following grain-to-milk ratios are observed.

	Level of production	Quality of hay	
		Good	Medium
	30	1:3.15	1:2.6
	40	1:3.50	1:2.95
	50	1:3.70	1:3.02
Pineapple bran fed:	30	0	4.9
	40	2.2	7.2
	50	4.7	8.6

Here again wider grain-to-milk ratios are observed for the good quality hay as compared to the medium quality hay. It is, however, noted that while the over-all grain-to-milk ratios decreased as production increased, the grain-to-milk ratios exclusive of pineapple bran widened with increase in production. This suggests that the palatable pineapple bran serves an important function of fulfilling nutritive needs when these needs are great as in the case of high-producing cows. The extent to which pineapple bran enters the ration is dependent upon the quality of roughage. This can be seen by comparing the amount fed along with good roughage and medium roughage for the three levels of production. Ultimately, the amount of substitution of hay for pineapple bran and vice versa will depend upon the relative prices of these two items and particularly upon the quality of roughage which can be provided. Quality will dictate to what extent roughage can be utilized in the ration. Pineapple bran, because of its very palatable nature and high energy content, can make up a large portion of the ration.

Some statement should be made about the molasses content of the concentrate mixture. Concentrates can contain up to 25 percent without causing a problem in mixing or feeding. The only limitation put on molasses was that each cow would receive no more than 4.5 pounds per day. For the animals receiving good quality hay producing at 30 pounds of milk and good quality hay producing at 40 pounds, the molasses as a percentage of the total concentrate mix exceeds 25 percent. If 10 percent molasses is added to the roughage the percentage of molasses will be reduced below the 25 percent level of the concentrate mix with the exception of the cows producing 30 pounds of milk and receiving good roughage. A solution for this group of cows would be to feed molasses free choice.

It is well to mention that the level of feeding to these cows is based upon the nutritional standards set forth in the beginning of this paper. Because of the favorable price for milk in Honolulu, it would be advisable to feed slightly in excess of these standards. The amount in excess will depend upon the individual and for this reason the minimal requirements were utilized in this programming.

For additional digestible protein and total digestible nutrients, one may refer to the penalty costs of forcing items into the ration for each level of milk production. Utilizing these figures, each dairyman may decide what level of feeding he desires and compute the cost of his ration.

When deciding upon the level at which to feed, consideration must be given to the size and range of milk production of the group of cattle being fed. Dairymen will achieve more efficient utilization of feed if the group of animals being fed are producing at about the same level of production. If a large group of cattle with a wide range in production are fed, feed will be wasted on the low producers in order to insure that the high producers receive a sufficient amount.

The decision on the size of the group of cattle will depend upon the facilities on the individual farm and the added labor to manage several small groups as compared to say 2 or 3 larger groups.

B. Economic Aspects

Linear programming provides a means by which least-cost rations can be formulated. The generation of each least-cost ration will depend on the following factors: (a) Price of all feed items, (b) assumed or known nutritional composition of all feeds, (c) feeding requirements or objectives, and (d) limitation on roughage and concentrate items entering the formulated ration.

To dairymen, this approach to feed formulation provides the essential information necessary to make decisions on the composition of his ration.

Linear programming of least-cost rations provides the following specific information to the dairyman: (a) The composition of a least-cost ration formulated from available feedstuffs, (b) tabulation of the price stability of each feedstuff, and (c) cost of substituting feedstuff in a least-cost ration.

This information would enable the dairyman to utilize those feeds which are least expensive while fulfilling the nutritive requirement of his cattle. From the tabulation of price stability, he would be in a position to determine if changes should be made in his ration in order to obtain a less expensive ration. If the dairyman was not satisfied with the least-cost ration, the cost of substituting feedstuff values would enable him to determine the cost of substituting a particular feedstuff in the least-cost ration. These values would also enable the dairyman to determine the cost of feeding additional protein or energy (TDN) to his cattle.

Linear programming would provide the necessary information for cost budgeting of rations and would serve as a sort of benchmark or point of departure for the construction of adjusted rations meeting particular feeding situations.

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